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Rotary Electric Machine and Manufacturing Method for Same

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[Claims]

[Claim 1] A rotary electric machine in which a stator winding is wound in concentrated fashion on multiple individual teeth provided on a stator,

characterized in that the stator winding is comprised of a multiple number k of winding elements provided on said individual teeth, a multiple number q of adjacent winding elements provided on said teeth connected in series to form a serial circuit, and a number k of said serial circuits connected in parallel.

[Claim 2] The rotary electric machine of claim 1 further characterized in that n denotes a positive integer and k = nq.

[Claim 3] The rotary electric machine of claim 1 or 2 further characterized in that, among the winding elements positioned on a single tooth, the winding direction of at least one of said winding elements differs from the winding direction of the other winding elements.

[Claim 4] The rotary electric machine of claim 1 or 2 further characterized in that the winding direction of all of the winding elements positioned on a single tooth is identical.

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[1] Numbers in the margin indicate pagination in the foreign text.

[Claim 5] The rotary electric machine of any of claims 1 to 4 further characterized in that an insulating member is positioned on at least a portion of the area between winding elements provided on a single tooth.

[Claim 6] The rotary electric machine of any of claims 1 to 5 further characterized in that the winding element provided on a single tooth is positioned to overlap itself radially.

[Claim 7] The rotary electric machine of claim 6 further characterized in that the potential of the outer circumference edge portion of the inside winding element is made equal to the potential of the inner circumference edge portion of the outside winding element in the space between adjacent winding elements provided on a single tooth.

[Claim 8] The rotary electric machine of any of claims 1 to 5 further characterized in that the winding element provided on a single tooth is arranged side-by-side in an axial direction.

[Claim 9] The rotary electric machine of any of claims 1 to 8 further characterized in that the connection between winding elements is made with the same wire material as said winding element.

[Claim 10] A rotary electric machine in which a stator winding is wound in concentrated fashion relative to multiple individual teeth provided on a stator,

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characterized in that the stator winding is comprised of multiple winding elements positioned side-by-side in an axial direction on each of said teeth, with said winding elements being connected in parallel.

[Claim 11] A method of manufacturing rotary electric machines in which a stator winding is wound in concentrated fashion on each of multiple individual teeth provided on a stator,

characterized in that winding elements are first sequentially wound one per tooth on each of said teeth, winding elements are then wound in sequence on said winding elements to form multiple winding elements on each of said teeth, the winding elements provided on multiple adjacent teeth are connected in series to form a serial circuit, and multiple serial circuits are connected in parallel to configure the stator winding.

[Claim 12] A method of manufacturing rotary electric machines in which a stator winding is wound in concentrated fashion on each of multiple individual teeth provided on a stator,

characterized in that one winding element is first wound on said tooth, the wire material is tied up to the terminal, a separate winding element is then wound in the opposite winding direction from the above winding element over said winding element to form multiple winding elements on said tooth, a move

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is made to the adjacent tooth and multiple winding elements are formed in the same order as above to configure the stator winding.

[Detailed Description of the Invention]

[0001]

[Technical Field of the Invention] The present invention relates to rotary electric machines such as electrical motors and methods of manufacturing the same, and in particular, to stator windings.

[0002]

[Prior Art] As an example of the winding structure of a prior art rotary electric machine in which windings are collectively wound on individual teeth, Japanese Patent Application Publication Heisei 09-285088 discloses a synchronous electric motor. Fig. 20 is a sectional view descriptive of such a prior art rotary electric machine. In the figure, the rotary electric machine is comprised of a stator 20 and a rotor 30. Stator 20 is comprised of a stator iron core 22 and a stator winding 24. Stator iron core 22 is comprised of a circular stator yoke 22A and a stator magnetic pole 22B. Stator winding 24 is wound in concentrated fashion on stator magnetic pole 22B. The configuration is such that no two stator windings 24 share a magnetic path on the surface of a void. Since such a stator

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configuration in which stator winding 24 is wound in

concentrated fashion in this manner permits shortening of the

length of the end coil element, it is possible to reduce the

size of the rotary electric machine. U1+, U1-, U2+, U2- are

connected to the U phase; V1+, V1-, V2+, V2- are connected to

the V phase; and W1+, W1-, W2+, W2- are connected to the W phase

of stator winding 24. Connecting an AC power source to stator

winding 24 generates a shifting magnetic field, yielding

rotating torque through interaction with rotor 30.

[0003]

[Problems to Be Solved by the Invention] In a rotary electric

machine of the above-stated configuration, due to power

constraints, it sometimes becomes necessary to reduce the

winding impedance as viewed from the power source. In such

cases, the number of windings is normally reduced by increasing

the wire diameter of the windings to reduce the resistance value

or impedance. When this is done, the current value increases by

an amount corresponding to the reduction in the number of turns.

When the number of ampere turns is kept constant, torque

characteristics are maintained. However, when a large-diameter

magnet wire is employed in this type of rotary electric machine

in which one winding is concentrated in each tooth, the rigidity

of the magnet wire is high. Thus, during the processing of the

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windings, various problems are generated by twisting, bending, and slipping. Further, the work space in which the winding is positioned is sometimes narrow, making it hard to achieve high-density windings.

[0004] To solve such problems, for example, Japanese Patent Application Publication No. Heisei 11-206054 discloses, as shown in Fig. 21, a technique of twisting multiple fine diameter magnet wires 11 to achieve a conductor sectional area equivalent to that of large-diameter wire, thereby increasing the space factor and increasing flexibility to permit ready winding into a rotary electric machine even in narrow work spaces. However, when extremely fine wire is twisted, as is done, for example, in high-frequency applications, there is a risk that the individual wires will break, and processing of the twisted wire is expensive, increasing the cost of the rotary electric machine. When the diameter of the individual wires is increased to prevent this, there are problems in that it becomes difficult to increase the space factor and workability. The present invention, devised to solve such problems, has for its object to achieve a high space factor and improved workability using fine wire material. A further object is to provide a method of

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manufacturing suited to mass production in which the number of steps and the number of parts are reduced.

[0005]

[Means of Solving the Problems] The rotary electric machine of claim 1 is a rotary electric machine in which the stator winding is wound in concentrated fashion relative to multiple individual teeth provided on the stator, with the stator winding being comprised of a multiple number k of winding elements provided on said individual teeth, a multiple number q of adjacent winding elements provided on said teeth connected in series to form a serial circuit, and a number k of said serial circuits connected in parallel. The rotary electric machine of claim 2 is the rotary electric machine of claim 1 wherein n denotes a positive integer and k = nq.

[0006] The rotary electric machine of claim 3 is the rotary electric machine of claim 1 or 2 further characterized in that, of the winding elements positioned on one tooth, the winding direction of at least one of said winding elements differs from the winding direction of the other winding elements. The rotary electric machine of claim 4 is the rotary electric machine of claim 1 or 2 further characterized in that the winding direction of all of the winding elements positioned on a single tooth is identical. The rotary electric machine of claim 5 is the rotary

electric machine of any of claims 1 to 4 further characterized in that an insulating member is positioned on at least a portion of the area between winding elements provided on a single tooth.

[0007] The rotary electric machine of claim 6 is the rotary electric machine of any of claims 1 to 5 further characterized in that the winding element provided on a single tooth is positioned to overlap itself radially. The rotary electric machine of claim 7 is the rotary electric machine of claim 6 further characterized in that the potential of the outer circumference edge portion of the inside winding element is made equal to the potential of the inner circumference edge portion of the outside winding element in the space between adjacent winding elements provided on a single tooth. The rotary electric machine of claim 8 is the rotary electric machine of any of claims 1 to 5 further characterized in that the winding element provided on a single tooth is arranged side-by-side in an axial direction. The rotary electric machine of claim 9 is the rotary electric machine of any of claims 1 to 8 further characterized in that the connection between winding elements is made with the same wire material as the winding element.

[0008] The rotary electric machine of claim 10 is a rotary electric machine in which a stator winding is wound in concentrated fashion relative to multiple individual teeth

provided on a stator, characterized in that the stator winding is comprised of multiple winding elements positioned side-by-side in an axial direction on each of said teeth, with the winding elements being connected in parallel.

[0009] The method of manufacturing a rotary electric machine of claim 11 is one in which a stator winding is wound in concentrated fashion on each of multiple individual teeth provided on a stator, characterized in that winding elements are first sequentially wound one per tooth on each of said teeth, winding elements are then wound in sequence on said winding elements to form multiple winding elements on each of said teeth, the winding elements provided on multiple adjacent teeth are connected in series to form a serial circuit, and multiple serial circuits are connected in parallel to configure a stator winding.

[0010] The method of manufacturing a rotary electric machine of claim 12 is one in which a stator winding is wound in concentrated fashion on each of multiple individual teeth provided on a stator, characterized in that one winding element is first wound on said tooth, the wire material is tied up to the terminal, a separate winding element is then wound in the opposite winding direction from the above winding element over said winding element to form multiple winding elements on said

tooth, a move is made to the adjacent tooth and multiple winding

elements are formed in the same order as above to configure a

stator winding.

[0011]

[Modes of Implementing the Invention] Implementation Mode 1.

This implementation mode is an example in which the number of

adjacent in-phase windings q = 2, the intermediate potential is

identical, and there is no intermediate insulating member. Fig.

1 is a sectional drawing, descriptive of the structure of the

rotary electric machine in Implementation Mode 1 of the present

invention, in which 1 denotes a cylindrical stator, 2 denotes a

rotor core, 3 denotes 12 teeth provided on stator core 2, and

4a-4L denote stator windings wound in concentrated fashion on

each of teeth 3.   An insulating member 8 is positioned between

teeth 3 and stator windings 4a-4L. Stator 1 is comprised of

stator core 2, stator windings 4a-4L, and insulating member 8.

7 denotes a rotor provided in the hollow portion of stator 1.

Fourteen permanent magnets 6 are arranged on the surface

thereof, opposite stator 1, so that the polarity of adjacent

permanent magnets 6 is mutually opposing.

[0012] The connections of the stator windings (referred to as

"windings" hereinafter) will be briefly described first.

Windings 4a-4L are divided into three groups and connected to a

three-phase alternating current power source, not shown. In the
present implementation mode, among the 12 windings 4a-4L, the
four windings 4a, 4b, 4g, and 4h are U-phase windings, the four
windings 4c, 4d, 4i, and 4j are W-phase stator windings, and the
four windings 4e, 4f, 4k, and 4L are V-phase windings. That is,
in this example, there are two adjacent in-phase windings. In

other words, the windings of two adjacent teeth 3 are in-phase
windings. Among the U-phase windings, the direction of current
flow is identical in windings 4a and 4h as viewed from the
center axis of the rotary electric machine, and the direction of
current flow in these two windings is the opposite of that in
windings 4b and 4g. The same applies to the V-phase and W-phase
windings.

[0013] Here, symmetry is taken into consideration in the phase
relation between the individual phase windings. Half of 12
windings 4a-4L, namely windings 4a-4f, will be used for
description. Due to the relation between the number of teeth 3
and the number of permanent magnets 6, each of windings 4a-4L
has a phase difference, or electrical angle, of $7\pi/6$. Among the
U-phase windings, the polarity of adjacent windings 4b having a
phase difference, or electrical angle, of $7\pi/6$ with winding 4a
is reversed. Accordingly, the induced voltage generated in each

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winding has a phase difference of π/6. Windings 4a and 4b are

connected in series. The serial circuit of windings 4a and 4b

is connected in parallel with the serial circuit of windings 4g

and 4h. The connections will be described in detail further

below.

[0014] Fig. 2 is a vector drawing of the relation between the

induced voltage of the individual windings and the composite

induced voltage of the individual phase windings. U1, U2, W1,

W2, V1, and V2 denotes the voltages of windings 4a-4f,

respectively. The polarity of windings 4b, 4c, and 4f is

reversed and they are connected in series with adjacent in-phase

windings 4a, 4d, and 4e. Thus, the polarity of U2, W1, and V2

is reversed and combines with U1, W2, and V1. Windings 4a-4L

are connected in a star shape, with the phase voltages of each

phase being denoted by U, V, and W, and having a mutual phase

difference of 2π/3. The remaining semicircle portion of stator

1, that is, the portion comprising tooth 7 and beyond, repeats

the windings of teeth 1 through 6 in reverse fashion.

[0015] Ultimately, as a combination of two voltage vectors

having a phase difference of π/6, voltages in multiples of

2cos(π/12) = 1.93185... of voltage v generated by windings 4a-4L

are produced in each phase. When there is no phase difference

between windings 4a and 4b, the composite induced voltage

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generated by the U-phase winding becomes 2v. The ratio thereof, that is, 1.93185.../2 = 0.9659... is referred to as the distribution coefficient. The stator windings thus connected are connected to a three-phase alternating current power source. When alternating current is flowing, a magnetic field is generated by the current in each tooth, and torque is generated by interaction with permanent magnet 6.

[0016] The winding structure will be described next more specifically with Figs. 3 through 6. Fig. 3 is a sectional view of the portion corresponding to adjacent in-phase windings 4a and 4b. In the figure, the "X" mark and black dot do not denote the direction of current flow, but denote winding direction. Winding 4a is comprised of winding element A1 positioned on the inside and winding element A2 positioned on the outside. Winding elements A1 and A2 are concentrically wound on tooth 3. At the same time, winding 4b is comprised of winding element B1 positioned on the inside and winding element B2 positioned on the outside. In the four winding elements A1, A2, B1, and B2, the portions where the windings start, that is, the edge portions of the inner winding on the side close to tooth 3, are denoted as VA1in, VA2in, VB1in, and VB2in, and the portions where the windings end, that is, the edge portions of the outer

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winding on the side removed from tooth 3, are denoted as VA1out, VA2out, VB1out, and VB2out.

[0017] Fig. 4 is a connection diagram showing winding connections. Of the four winding elements A1, A2, B1, and B2, since there is a difference in wire length between winding elements A1 and B1 positioned on the inside and winding elements A2 and B2 positioned on the outside, there is potentially a difference in resistance values. Due to the difference in distance from the iron core (tooth 3), there is also potentially a difference in impedance. However, as shown in Fig. 4, by connecting in series winding elements A1 and B2, and winding elements A2 and B1, any imbalance in impedance between the two serial circuits is prevented and it is possible to inhibit the generation of a circulating current when the two serial circuits are connected in parallel. As will be understood from Fig. 4, the intermediate potential, that is, the outer winding edge VA1out of winding element A1 and the inner winding edge VA2in of winding element A2, have roughly the same potential. Since there is almost no difference in potential produced between the inner circumference side of winding element A1 and the outer circumference side of winding element A2, there is no need to provided an insulating member. The same holds true for winding elements B1 and B2.

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[0018] The winding method will be described next with Figs. 3 and 5. Fig. 5 is a drawing descriptive of the winding method. Starting from terminal 41, winding element A1 on the inside of winding 4a is sequentially wound from VA1in -> VA1out. After finishing winding of A1, the winding on terminal 43 is tied up to terminal 43, and continuing in that manner, winding element A2 is sequentially wound from VA2in -> VA1out. The winding directions of winding elements A1 and A2 are opposite. Once winding of A2 has been completed, the winding is tied up to terminal 42, and continuing in that manner, the winding is tied up to the terminal 45 on the neighboring tooth. Subsequently, in the same manner, winding is conducted in the order terminal 45 -> winding element B1 -> terminal 46 -> winding element B2 -> terminal 44, after which it is tied up to initial terminal 41 to end the winding operation. Subsequently, on terminals 41-46, a method such as fusing (heat crimping) the windings to the terminals is employed to make and secure the connections.

[0019] In the same manner as set forth above, connections are made with adjacent in-phase windings other than 4a and 4b, these are connected in parallel for each phase, and a star-shaped connection is formed to configure a three-phase winding such as is shown in Fig. 6.

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[0020] Forming connections by the procedure set forth above makes it possible to continuously process windings using the same wire for adjacent in-phase windings and the connections between them, as well as reducing the number of steps. Further, as will be understood from Figs. 4 and 5, terminals 43 and 46 serve as the terminals of the two windings 4a and 4b, and terminals 41, 42, 44, and 45 pick up the intermediate potential. When an equivalent power source 47 is connected for each phase, current i2 flows to winding elements B2 and A1 and current i1 flows to winding elements B1 and A2. This value is determined

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by the respective impedances. However, as set forth above, since the impedances of winding elements B1 and A1, and B2 and A2, are nearly equal, currents i1 and i2 can be rendered nearly equal.

[0020] In the present implementation mode, although an example has been given in which the windings of individual phases, such as 4a and 4b, 4g and 4h, are connected in parallel, a serial connection such as that shown in Fig. 7 is also possible by balancing with the power capacity. Although the example of a three-phase star-shaped connection has been given, a triangular connection is also possible. In that case, so long as the

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source voltage is identical, the current decreases as the number of windings increases.

[0022] Implementation Mode 2. The present implementation mode is an example in which the number of adjacent in-phase windings q=2, the intermediate potential is identical, and there is no intermediate insulating member. Fig. 8 is a drawing descriptive of the winding method in Implementation Mode 2; the description of components identical to those in Fig. 5 is omitted. In the present implementation mode, terminals 51 and 56, 52 and 55, 53 and 54, and 57 and 58 are connected by means of connecting members 59, 60, 61, and 62, respectively. This winding method will be described below.

[0023] Starting at terminal 53, winding element A1 on the inside of winding 4a is wound and the winding is tied to terminal 52. Next, starting from terminal 51, winding element A2 is wound in the opposite direction from winding element A1 and the winding is tied to terminal 54. Similarly, winding is conducted in the sequence terminal 57 -> winding element B1 -> terminal 56, and terminal 55 -> winding element B2 -> terminal 58, and winding is concluded. Finally, at each terminal, the winding and terminal are connected and secured by a means such as fusing. The remainder is identical to that in Implementation Mode 1. In the present implementation mode, the winding operation cannot be

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continuously conducted and a cutting operation is required for each winding element. However, since connections between the individual winding elements are made with insulating members 59-62, the time required for winding is shortened.

[0024] The present implementation mode gives an example in which the winding of winding element A2 is conducted following the winding of winding element A1. However, since each winding element can be independently wound, the winding of winding element B1 after winding element A1 is also possible. In that case, in all winding over the entire circumference, after winding on the inner circumference side in one direction, it is possible to wind in on the outer circumference side in the opposite direction. Thus, there is an increase in the degree of freedom in processing steps permitting, for example, the use of separate winding machines for the inner circumference and outer circumference sides.

[0025] Implementation Mode 3. The present implementation mode is an example in which the number of adjacent in-phase windings q=2, the intermediate potential is not identical, and there is an intermediate insulating member. Fig. 9 is a sectional view of adjacent in-phase windings descriptive of the winding method in Implementation Mode 3 of the present invention. Fig. 10 is winding schematic. Fig. 11 is a drawing describing the winding

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method. In these figures, the description of components identical to those found in Fig. 3 through 5 is omitted. Differing from Implementation Modes 1 and 2, in the present implementation mode, as will be understood from figures 9 through 11, all winding elements are wound in the same direction. Terminals 71 and 76, 72 and 75, 73 and 74, and 77 and 78 are connected by connection members 79, 80, 81, and 82, respectively. The winding method will be described below.

[0026] First, starting from terminal 73, winding element A1 on the inside of winding 4a is wound and the winding is tied to terminal 72. Next, starting from terminal 74, winding element A2 is wound in the same direction as winding element A1 and the winding is tied to terminal 71. Similarly, winding is conducted in the sequence terminal 77 -> winding element B1 -> terminal 76, terminal 78 -> winding element B2 -> terminal 75 and the winding operation is ended. Finally, each terminal is connected and secured by a method such as fusing the winding to the terminal.

[0027] In this case, the potential of VA1out, which is the potential on the winding end side of winding element A1, cannot be made identical to the potential of VA2in, which is the potential on the winding start side of winding element A2. Thus, an insulating member 9 is provided between winding element

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A1 and A2. Insulating element 9 may be in the form of a
tapelike member that is wound over the winding, or a platelike
resin that is inserted. When the difference in potential is
adequately low, insulating member 9 can be omitted. The
remainder is identical to Implementation Mode 1.

[0028] The present implementation mode gives the example of the
winding of winding element A2 after the winding of winding
element A1. However, since each winding element is
independently wound, the winding of winding element B1 following
the winding of winding element A1 is also possible. In that
case, in all winding over the entire circumference, it is
possible to wind on the inner circumference side and then wind
in the same direction on the outer circumference side. Thus, it
is possible to employ separate winding machines on the inner
circumference side and the outer circumference side, and well as
continuously execute operations on each of teeth 3 during
positioning of insulating member 9, increasing the degree of
freedom in processing steps.

[0029] Implementation Mode 4. The present implementation mode
is an example in which windings are divided in the radial
direction of the rotary electric machine. Fig. 12 is a
sectional view near windings 4a and 4b descriptive of the
winding method in Implementation Mode 4 of the present

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invention. The description of components identical to those in Fig. 9 is omitted. In the winding method of the present implementation mode, two winding elements A1 and A2 comprising winding 4a are aligned in the radial direction of the rotary electric machine and separated by means of an insulating member 10. That is, it is positioned to separate the bottom of a slot in the form of the space between windings positioned between teeth from the opening portion side of the slot. The remainder is identical to Implementation Mode 3.

[0030] In such a configuration, there is almost no impedance exhibited by winding elements A1 and A2, in effect increasing the degree of freedom. That is, after connecting winding element A1 and B2, and A2 and B1, in series, it is desirable to connect them so that they are parallel. However, when the winding elements are positioned as in the present implementation mode, there is almost no difference in impedance. Thus, after connecting winding elements A1 and B1, and A2 and B2, in series, they can be connected in parallel.

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[0031] Implementation Mode 5. The present implementation mode is an example in which the number of adjacent in-phase windings is q = 3. Fig. 13 is a sectional view descriptive of the structure of the rotary electric machine of Implementation Mode 5 of the

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present invention. Fig. 14 is a sectional view of adjacent in-phase windings. Fig. 15 is a schematic of the same. In these figures, the description of components identical to those in Figs. 1, 9, and 10 is omitted. The present implementation mode, as shown in Fig. 13, is an example in which the number of permanent magnets 6 serving as poles is 16 and the number of teeth 3 is 18. In this case, the number q of adjacent in-phase windings is generally made three. For example, among the 18 windings, 4a, 4b, 4c, 4j, 4k, and 4L are connected to the U phase; 4d, 4e, 4f, 4m, 4n, and 4o to the W phase, and 4g, 4h, 4i, 4p, 4q, and 4r to the V phase.

[0032] Fig. 14 is an enlargement of the three windings 4a, 4b, and 4c among the U phase windings. Windings 4a, 4b, and 4c are comprised of winding elements A1-A3, B1-B3, and C1-C3, respectively. Fig. 15 is descriptive of these connections: a winding in which A1, B2, and C3 are serially connected; a winding in which A2, B3, and C1 are serially connected; and a winding in which A3, B1, and C2 are serially connected are connected in parallel. The remainder is identical to Implementation Mode 3. Such a configuration permits an increase in the number of parallel circuits while inhibiting the current circulating due to an imbalance in the impedance of individual winding elements. That is, as in Implementation Modes 1-4, it

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is possible to reduce the winding impedance as viewed from the power source while making windings using conductive wire of small diameter.

[0033] The present Implementation Mode is an example in which respective winding elements are wound in the same direction on individual teeth 3. In this case, as in Implementation Mode 3, since the intermediate potential does not match and a potential difference is generated between adjacent winding elements, an insulating member 9 is provided. Some or all of insulating members 9 can be eliminated if effort is expended on the winding direction to prevent the generation of a potential difference. In the description set forth above, although the case is given where the winding elements in each of teeth 3 are divided into the three parts of the inner circumference side near the tooth, the outer circumference side removed from the tooth, and the portion between, this is not by way of limitation. For example, as shown in Fig. 16, in the same manner as in Implementation Mode 4, it is also possible for the winding elements in an individual tooth to be arranged side by side in the radial direction of the rotary electric machine and an insulating member 10 used to separate them.

[0034] Implementation Mode 6. The present implementation mode is one in which there is no adjacent in-phase winding; that is,

q = 1. Fig. 17 is a sectional view descriptive of the configuration of the rotary electric machine of Implementation Mode 6 of the present invention. Fig. 18 is a section view of an enlargement of winding 4a. In the figures, the description of components identical to those in Figs. 1 and 3 is omitted. The present implementation mode of the present invention, as shown in Fig. 17, is an example in which the number of permanent magnets 6 serving as poles is four and the number of teeth 3 is six. In this case, one adjacent in-phase winding is usually employed (q=1). The remainder is identical to that in Implementation Mode 1.

[0035] In this case, it is not possible to use the method disclosed in Implementation Mode 1 of canceling the imbalance in impedance by making serial connections between adjacent teeth in advance. Thus, so as to render the impedances of two coils wound on a single tooth as close as possible, they are arranged separately in the radial direction of the rotary electric machine; that is, two winding element elements A1 and A2 are positioned side by side on the slot bottom side and on the slot opening side. Numeral 10 denotes an insulating member positioned between the winding elements. By arranging the winding elements in this manner so that they are connected in parallel to connect the three phases, as shown in Fig. 19, the

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number of parallel circuits can be made even larger than the number of teeth.

[0036] Implementation Modes 1-6 of the present invention have been set forth above. In the above implementation modes, cases where the number of adjacent in-phase windings is from one to three have been described. However, this is not by way of limitation, and q may assume any value. Cases are described where the number of winding elements wound on a single tooth, k, is k = 2 when q = 1, and where k = q when q = 2 or 3. However, this is not by way of limitation; k may be equal in value to q, or may be some integer multiple of q, and the same effect as in the above implementation modes can be achieved. Further, when q = 2, k = 3, and winding elements are stacked on top of each other and connected in serial to the winding elements of adjacent teeth, the same effect can be achieved by combining outer, inner, and middle winding elements into connections. Further, in the implementation modes set forth above, cases where three-phase windings are configured are described. However, this is not by way of limitation; the case is the same with windings of any number of phases. Further, the case of employing permanent magnets on the rotor side is disclosed. However, the rotor configuration is not limited thereto. The

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same effect can be achieved not just in the operation of electric motors, but also in the operation of generators.

[0037]

[Effect of the Invention] In the rotary electric machine of claim 1, since the winding elements of q adjacent teeth are connected in series and the serial circuits are connected in parallel, it is possible to increase the number of parallel conductors in stator windings, and employ fine, flexible conducts, thereby enhancing workability. This also improves the space factor. In the rotary electric machine of claim 2, since k = nq, balancing of impedance is readily achieved by symmetrical positioning.

[0038] In the rotary electric machine of claim 3, since at least one of the winding directions of the winding elements differs from the others, it is possible to inhibit the potential difference of adjacent components in the winding elements. In the rotary electric machine of claim 4, since the winding direction of all winding elements is identical, automated winding is readily achieved. In the rotary electric machine of claim 5, since an insulating member is provided between winding elements, insulation breakdown is prevented.

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[0039] In the rotary electric machine of claim 6, since the winding elements are stacked in the radial direction, winding automation is readily achieved. In the rotary electric machine of claim 7, since the potentials of the outer circumference edge of the inside winding element and the inner circumference side of the outer winding element are made equal, winding automation is readily automated and it is unnecessary to employ insulating elements to prevent insulation breakdown between winding elements.

[0040] In the rotary electric machine of claim 8, since the winding elements are arranged side by side in a radial direction, it is possible to render the impedance between winding elements equal. In the rotary electric machine of claim 9, since the connection between winding elements is made with the same wire material as employed in the winding elements, the number of parts is reduced.

[0041] In the rotary electric machine of claim 10, since winding elements are positioned side by side in an axial direction and connected in parallel, the number of parallel circuits can be increased while balancing impedance even when q = 1.

[0042] In the method of manufacturing a rotary electric machine of claim 11, since one winding element is wound sequentially on each tooth, after which other windings are wound thereover on

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individual teeth, the degree of freedom in processing steps is increased in the use of winding machines and the mounting of insulating members, for example.

[0043] In the method of manufacturing rotary electric machines of claim 12, since following the winding of a winding element, it is tied to the terminal, after which another element is wound over the first winding element, and moving on to the adjacent tooth, the same procedure is conducted to wind winding elements, it is possible to continuously wind with the same winding material that is used in adjacent in-phase windings and in making connections therebetween. Accordingly, the number of steps and the number of parts can be reduced.

[Brief Description of the Figures]

[Fig. 1] A sectional view of the rotary electric machine in Implementation Mode 1 of the present invention.

[Fig. 2] A vector diagram descriptive of the relation between voltages in Implementation Mode 1 of the present invention.

[Fig. 3] A sectional view of the winding portion in Implementation Mode 1 of the present invention.

[Fig. 4] A schematic of the windings in Implementation Mode 1 of the present invention.

[Fig. 5] A descriptive drawing of the winding method in Implementation Mode 1 of the present invention.

[Fig. 6] A schematic diagram of all windings in Implementation Mode 1 of the present invention.

[Fig. 7] A schematic of another example of all windings in Implementation Mode 1 of the present invention.

[Fig. 8] A descriptive drawing of the winding method in Implementation Mode 2 of the present invention.

[Fig. 9] A sectional view of the winding portion in Implementation Mode 3 of the present invention.

[Fig. 10] A schematic of the windings in Implementation Mode 3 of the present invention.

[Fig. 11] A descriptive drawing of the winding method in Implementation Mode 3 of the present invention.

[Fig. 12] A sectional view of the winding portion in Implementation Mode 4 of the present invention.

[Fig. 13] A sectional view of the rotary electric machine in Implementation Mode 5 of the present invention.

[Fig. 14] A sectional view of the winding portion in Implementation Mode 5 of the present invention.

[Fig. 15] A schematic of the windings in Implementation Mode 5 of the present invention.

[Fig. 16] A section view of another example of the winding portion in Implementation Mode 5 of the present invention.

[Fig. 17] A sectional view of the rotary electric machine in Implementation Mode 6 of the present invention.

[Fig. 18] A sectional view of the winding portion in Implementation Mode 6 of the present invention.

[Fig. 19] A schematic of the overall winding in Implementation Mode 6 of the present invention.

[Fig. 20] A sectional view of a conventional rotary electric machine.

[Fig. 21] A sectional view of twisted wire in a conventional rotary electric machine.

[Key to the Numerals]

1 Stator; 3 tooth; 4a-4r stator windings; 8, 9, 10 insulating members; 41-46, 51-58, 71-78 terminals; 59-62, 79-82 connecting members; A1-A3, B1-B3, C1-C3 winding elements.

[図4]

[Fig. 4]

[図10]

[Fig. 10]

31

【図1】

1 : 固定子
3 : ティース
4 a～4 L : 固定子巻線
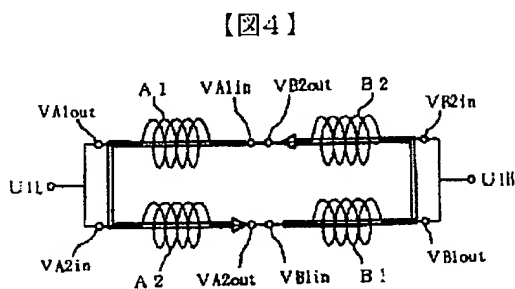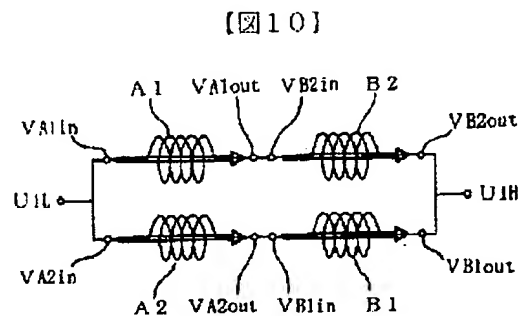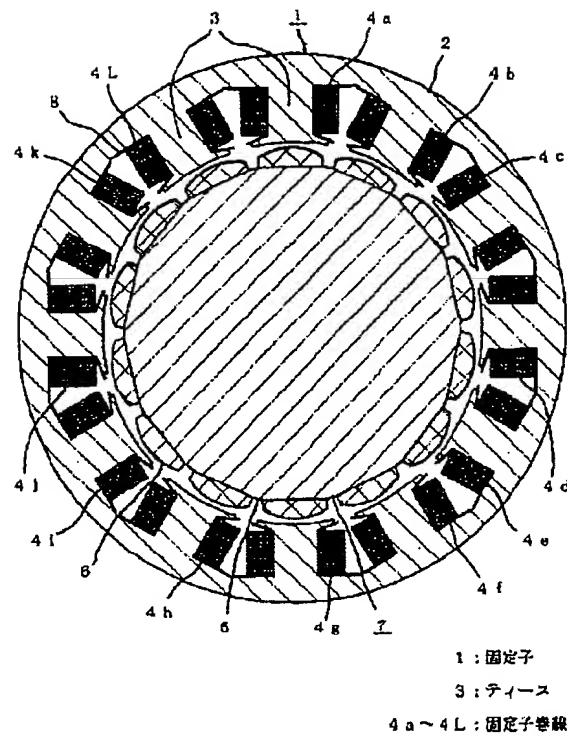
[Fig. 1]

1: Stator

3: Tooth

4a-4L: Stator windings

【図2】

[Fig. 2]

【図3】

A1, A2, B1, B2：巻線要素
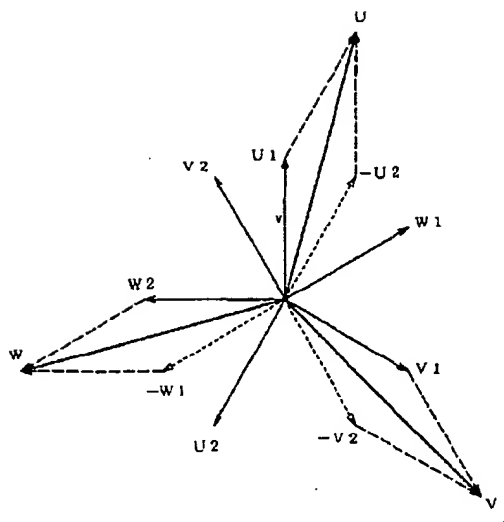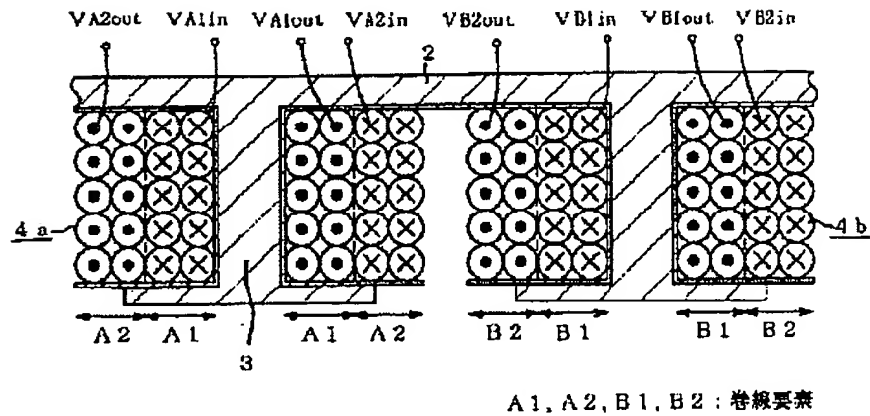
[Fig. 3]

A1, A2, B1, B2: Winding elements

【図6】
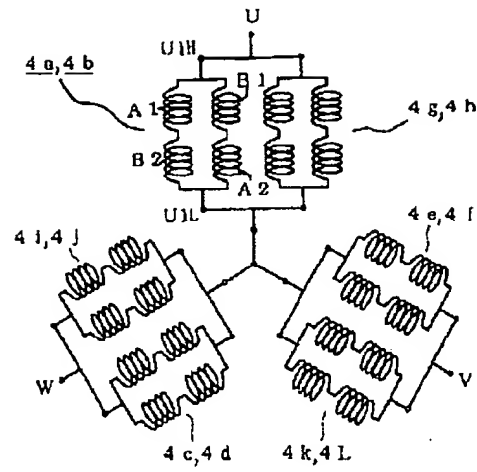
[Fig. 6]

【図9】

[Fig. 9]

9: Insulating member

34

【図18】

VA2out VA1out VA2in VA1in

2

10

A1

A2

4a

3

[Fig. 18]

/9

【図5】

47

U1L   U1H

42   41   43   44   45   46

VA2out VA1in   VB1out VB2in

VA1out VA2in   VB1in

VB2out

i2   i2

11   11

A1   B1

A2   B2

4a   3   4b

41～46：端子
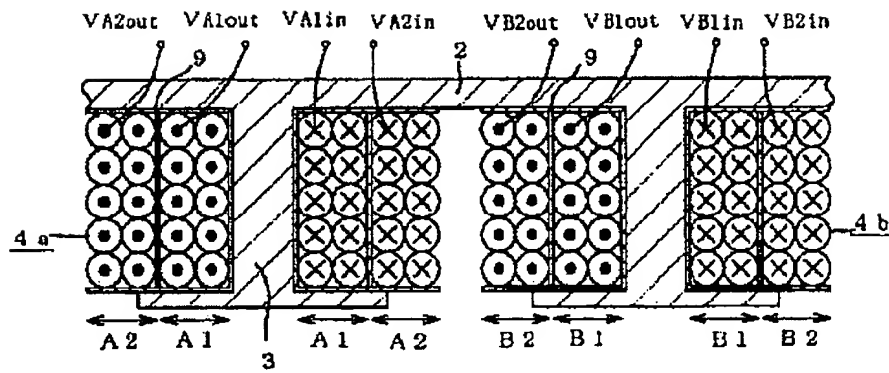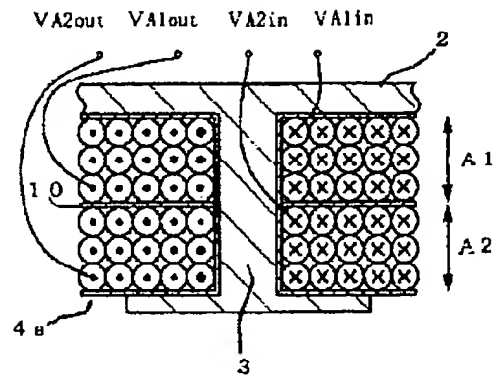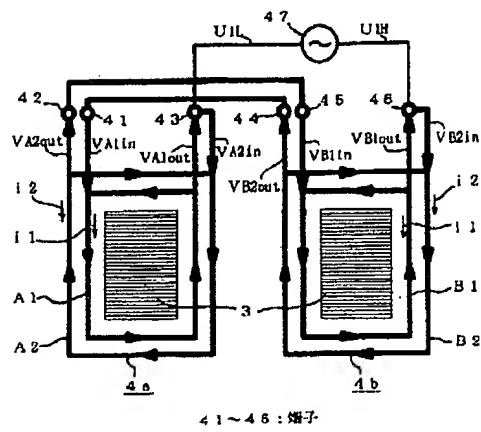
[Fig. 5]

41-46: Terminals

35

【図7】
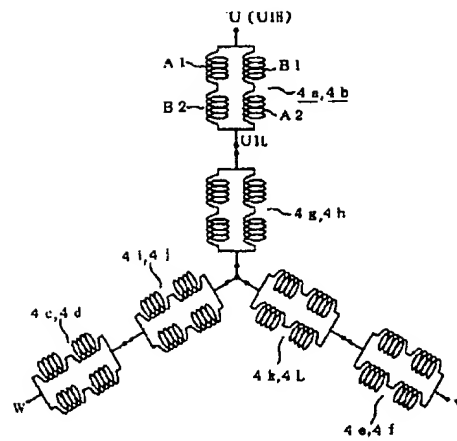
[Fig. 7]

[Fig. 8]

【図11】
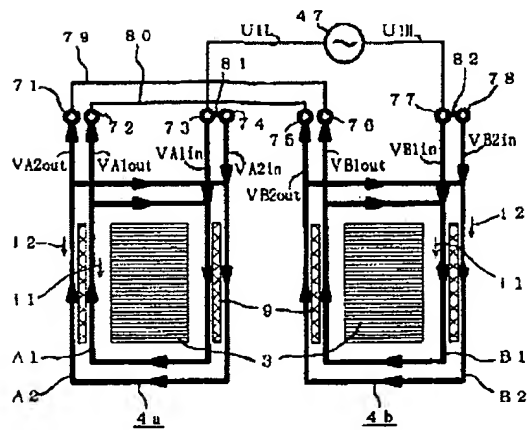
[Fig. 11]

【図12】
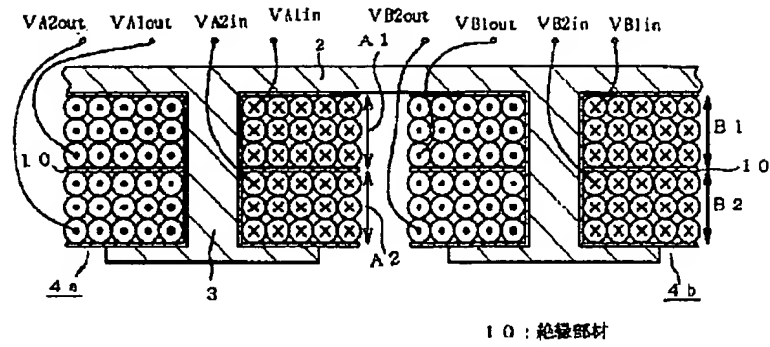
[Fig. 12]

10: Insulating member

【図21】

[Fig. 21]

/10

【図13】

4 m～4 r：固定子巻線
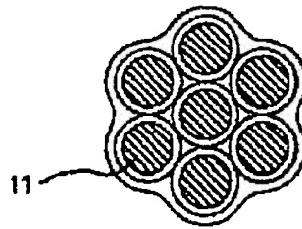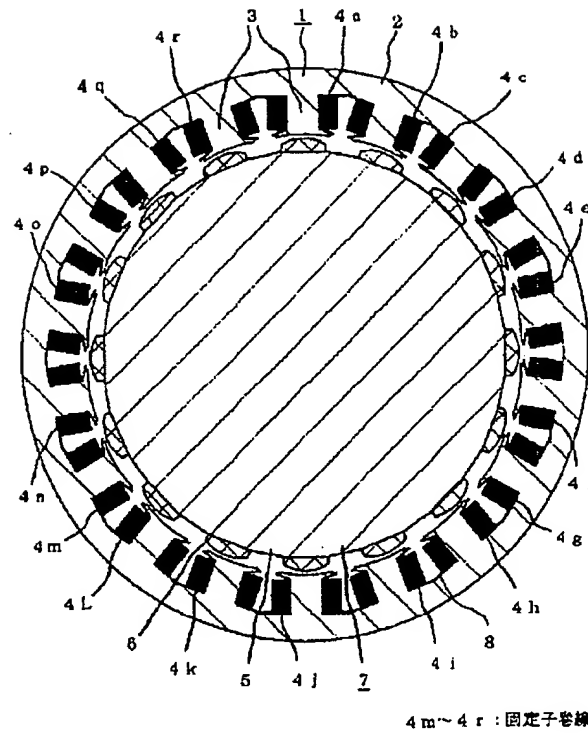
[Fig. 13]

4m-4r: Stator windings

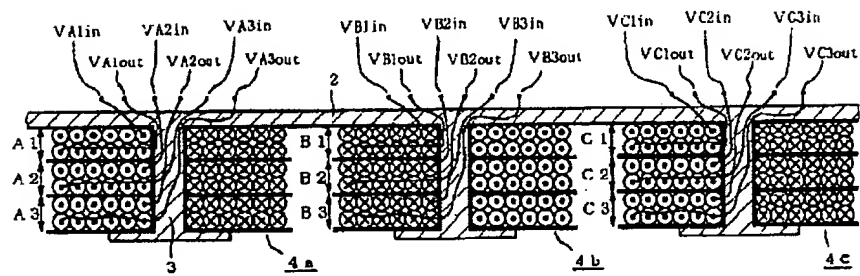【図14】

A 3．B 3．C 1～C 3：巻線要素
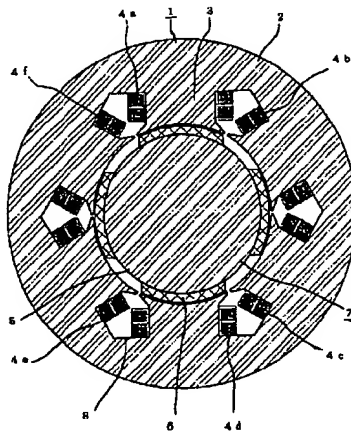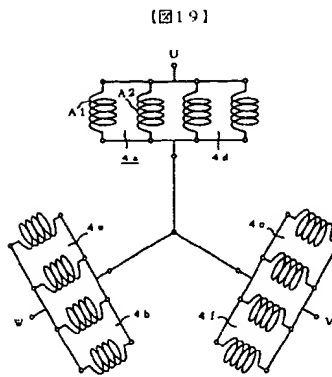
[Fig. 14]

38
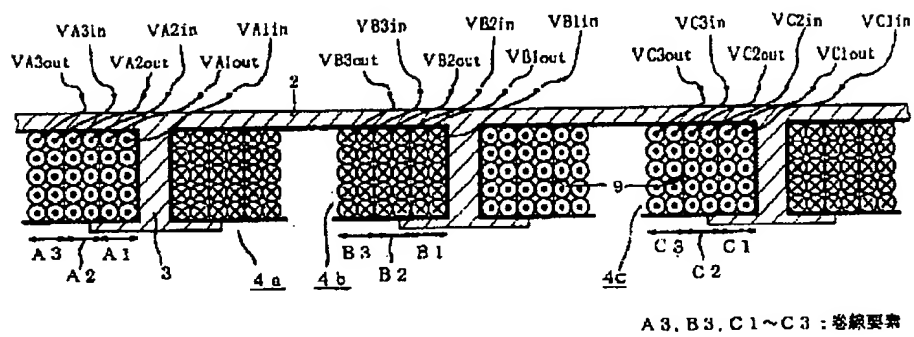
A3, B3, C1-C3: Winding elements

【図15】

[Fig. 15]

【図16】

[Fig. 16]

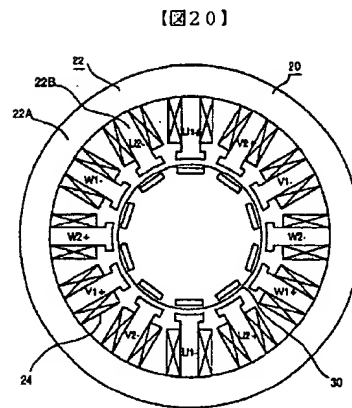【図17】

39

[Fig. 17]

[図19]

[Fig. 19]

[図20]

[Fig. 20]

40